VIBRATION BASED MEMS FOR PIEZOELECTRIC ENERGY HARVESTING

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

Certified that this project report **"VIBRATION BASED MEMS FOR PIEZOELECTRIC ENERGY HARVESTING"** is the bonafide work of "**K.HARISH, K.MUTHUKUMARAN, and S.SUBRAMANIAN"** who carried out the project work under my supervision.

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ABSTRACT

The wireless micro sensor marketing is growing quickly yet it is limited by short life time batteries. The use of piezoelectric material to capitalize on vibrations surrounding a system is one method for power harvesting. This project concentrates on production of electrical energy with the help of a piezoelectric crystal. The whole system consist of a cantilever beam (one end fixed and the other end is free), a piezoelectric crystal, a mass. Hence load is applied to make the piezoelectric crystal resting on the cantilever beam to vibrate. This vibration of the piezoelectric crystal results in the production of voltage in milliamps. The amount of electrical energy is directly proportional to the amount of load applied. The electrical energy is used as alternate way for sourcing wireless micro sensors.

Key Words: MEMS (Micro Electro Mechanical System), Micro cantilever, PZT (Lead Zirconate tianate), Micro power generator.

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CHAPTER 1

INTRODUCTION

Micro Electro Mechanical Systems (MEMS) has taken the field of technology to a new level. Over the past few years, the development of wireless sensor network application has generated much interest. Many difficulties arises, when replacing the batteries or in terms of recharging batteries of wireless micro sensors. This project helps in delivering energy to these micro sensors devices using piezoelectric micro generators. A piezoelectric crystal produces voltage on application of force or load on it causing deformation of the crystal. This phenomenon is known as piezoelectric effect. Here a cantilever beam is designed in such a way that it has a piezoelectric crystal attached to it on top and tends to vibrate when placed in a vibrating medium. Hence this piezoelectric phenomenon is employed to produce electrical energy which is required for the actuation of the MEMS devices.

OBJECTIVE

The objective of this project is to generate electrical energy by means of application of piezoelectric effect which is an alternative way of energy generation. To perform analysis and to determine voltage, displacement and Frequency for different amount of force applied.

CHAPTER 2

LITERATURE REVIEW

1. ENVIRONMENTAL VIBRATION BASED MEMS PIEZOELECTRIC ENERGY HARVESTING

- **Salem Saadon and Othman Sidek, University Sains Malaysia(USM)**

In this paper, the piezoelectric generators act as an alternate power source for traditionally used power source. In piezoelectric micro generators–mechanical vibrations is converted to electrical energy using piezoelectric crystals. Improvement in harvesting power from micro generator is done by two methods. First method by selecting the coupling mode of operation, practically there are two types of mode:

- First mode - d31 mode
- Second mode - d33 mode

Exited vibration force is applied perpendicular to the polling direction is known as d31 mode and vibration force parallel to the polling direction is known as d33 mode. In many cases d31 mode of operation is used.

Then second method by changing the device configuration by adding multiple piezoelectric materials to the harvester. The thin film cantilever beam is designed and maximum power of 0.038μW at resonant frequency of about 204 Hz.

The proof mass dimensions are varied to sustain the resonant frequency of the cantilever beam. The output power of MEMS micro generators is much less than to use as the dc power source for recently used equipments as well as sensors.

2. PIEZOELECTRIC MEMS POWER GENERATORS FOR VIBRATION ENERGY HARVESTING

- Wen Jong Wu and BorShiun Lee

The study is done on the comparison of different energy sources, which is suitable for MEMS technology. Then comparison of energy sources results in mechanical vibrations, which act as a potential power sources that can easily adopted with the micro electrical mechanical systems.

Mechanical vibration energy can be converted to usable electrical energy through piezoelectric, electrostatic and electromagnetic transducer. Piezoelectric transducer considered as the potential choice when compared with electrostatic and electromagnetic transducers.

Then cantilever beam model is designed for both d31 and d33 mode of operation. Then output performance of d31 mode and d33 mode of operation at acceleration of 2g is compared. The output power generated by d31 piezoelectric cantilever beam is about 2.099μW at resonant frequency of 255.9 Hz. Then output power by d33 mode is 1.288μW at resonant frequency of 214.0 Hz. The d31 mode has better output characteristics then that of d33 mode piezoelectric beam.

3. MEMS STRUCTURE FOR ENERGY HARVESTING

-ShadabRabbani, IIT, New-Delhi.

In this paper, piezoelectric cantilever beam is investigated by COMSOL finite element analysis for generation of electrical energy. A piezoelectric cantilever placed in the oscillatory environment produces strain, which in turn produces stress that results in generation of electric potential. Then electric potential attains maximum peak value when resonant frequency of cantilever beam matches with the natural frequency in environment and it dies out when mismatches. The multilayer piezoelectric cantilever beam is designed for different length and thickness. Then resonant frequency for different length and thickness is analysed. An increases in length, decreases the resonant frequency and increases in thickness, increases it. The maximum power generated by the beam is about 9μW at the exited mechanical vibration of $40N/m^2$. Then simulation results suggested that these structures can used for energy generation in wireless sensors.

CHAPTER 3

METHODOLOGY

3.1 MEMS

The term MEMS is the abbreviation of Micro Electrical Mechanical System. MEMS is the process technology used to create tiny integrated devices or systems that combine mechanical and electrical components. They are fabricated using integrated circuit batch processing techniques it contains the components of sizes in 1micrometer to 1 millimeter. MEMS device is constructed to achieve a certain engineering functions or functions by electromechanical or electrochemical means. These devices have abilities to sense control and actuate on micro scale and generate effects on macro scale. The core element in MEMS generally consists of a two principle components namely

- Sensing or actuating element
- Signal transmission unit.

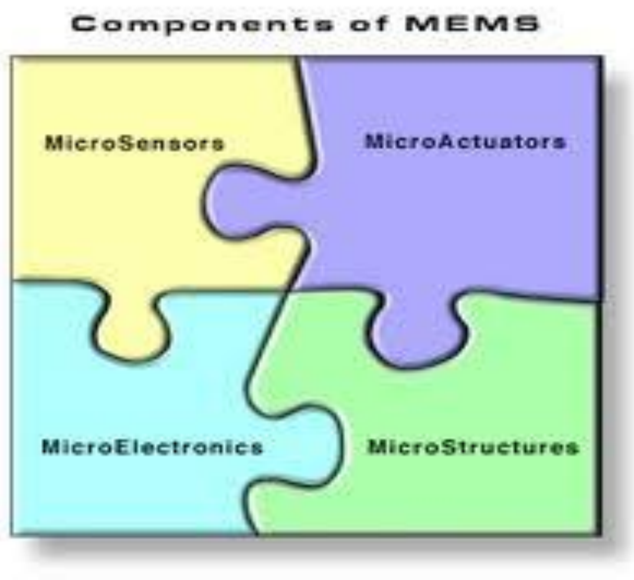

Figure1.Components of MEMS

3.2CANTILEVER BEAMS

Cantilever is the beam anchored at only one end. The beam used to carry loads at its free end .In micro electro mechanical systems, cantilever beams are the most ubiquitous structures in field. An example for MEMS cantilever is resonistor. MEMS cantilever are commonly fabricated from silicon or silicon nitrate or polymers. Large no of research groups are attempting to develop cantilever array for energy harvesting. Mostly MEMS cantilevers are commonly made as unimorph and biomorph.

TYPES OF CANTILEVER BEAM

UNIMORPH

Unimorph is a cantilever consists of two layers. In this cantilever, one is active layer and another is inactive layer. In the case where active layer is piezoelectric crystal and inactive layer may be an elastic medium. Then active layer and inactive layer are constructed as shown in figure given below. The deformation in that layer may be induced by the application of an electric field. This deformation induces a bending displacement in the cantilever.

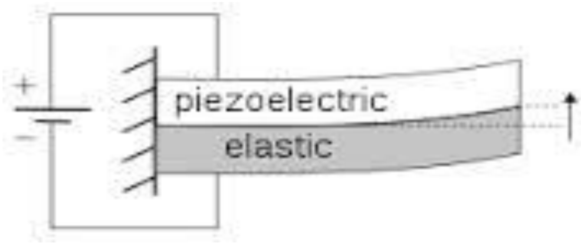

Figure 2.Unimorph

Mostly the inactive layer may be fabricated from a non-piezoelectric material.

BIOMORPH

A biomorph is a cantilever that consists of two layers. Here two layers are active layers. Then the layers may be a piezoelectric and metal. These layers produce a displacement by following two methods

THERMAL ACTIVATION

The thermal activation is one of way for displacement. Here in this thermal activation, temperature causes any one layer to expand more than other layer. The nature of heat is caused by the vibration of atoms and electrons in the material. The more an atom in the crystal is vibrating, results to elevated temperature and will excite atoms around it. Now consider all atoms from a material part are strongly vibrating. They will have a tendency to expand any one active more than other layer. This phenomenon is the thermal expansion.

ELECTRICAL ACTIVATION

Electrical activation is more over related to that of piezoelectric effect. As in piezoelectric bimorph, electric field causes one layer to extend and the other layer to contract. Thus the displacement can achieved, when electric field is applied to the crystal.

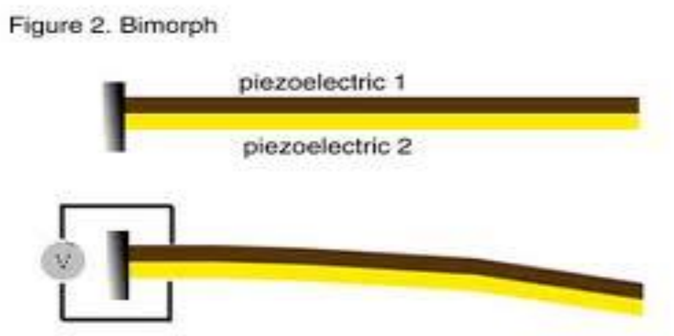

Figure 3.Electrical activation

3.2.1 CONSTRUCTION

The cantilever beam is constructed with the configuration as shown in the figure5. The structure consists of silicon base frame, silicon beam, the piezoelectric material, platinum electrodes and silicon proof mass. From the fixed end of silicon beam, a piezoelectric crystal which is sandwiched between two platinum electrodes is placed. For silicon beam, silicon on insulator is act as the wafer. Silicon dioxide, act as insulating material for the silicon beam. At the bottom of platinum electrode insulator is placed. Titanium is also used to improve the adhesion between platinum electrodes. As then silicon base frame is placed on the vibrating medium. At free end, silicon proof mass is placed.

DIMENSIONS OF CANTILEVER BEAM

Materials	Length(μm)	Thickness(μm)	Width(μm)
Silicon beam	2000	8	800
Silicon (proof mass)	1000	300	800
Pt electrode1	400	0.5	800
Pt electrode2	500	0.5	800
SiO^2 1&2	2000	0.3	800
SiO^2 3	1000	0.3	800
PZT	400	1	800

Table 1.Dimensions of cantilever beam

The above table describes the dimensions used for design of cantilever beam. The beam configuration is a structure consisting of a silicon base frame, Si beam, a piezoelectric element (PZT) layer sandwiched between a pair of metal, and a Silicon proof mass at the free end. The device has been designed for different lengths and different thicknesses. An increase in length decreases the resonant frequency of the cantilever and an increase in the thickness increases it. Si at the free end tip was use as the proof mass (0.5592μg; dimensions: 1000μm x 800μm x 300μm) to decrease the resonant frequency. The top Si layer of SOI (Silicon on Insulator) wafer was used as the bulk of cantilever material. SiO_2 (500nm thick) was used as the insulator between the bottom electrode Pt (thickness 300nm). Ti was used as the adhesion layer to improve the adhesion between PZT (thickness 1μm) and Pt electrode and to facilitate the growth of the PZT crystal.

3.3 PIEZOELECTRIC EFFECT

Definition

Crystals which acquire a charge when compressed, twisted or distorted are said to be piezoelectric crystals. This provides a convenient transducer effect between electrical and mechanical oscillations also piezoelectric substance is one that produces an electric charge when a mechanical stress is applied. Conversely, a mechanical deformation is produced when an electric field is applied. This effect is formed in crystals that have no center of symmetry. To explain this, we have to look at the individual molecules that make up the crystal. Each molecule has a polarization, one end is more negatively charged and the other end is positively charged, and is called a dipole. This is a result of the atoms that make up the molecule and the way the molecules are shaped. The polar axis is an imaginary line that runs through the center of both charges on the molecule. In a monocrystal the polar axes of all of the dipoles lie in one direction. The crystal is said to be symmetrical because if you were to cut the crystal at any point, the resultant polar axes of the two pieces would lie in the same direction as the original. In a polycrystal, there are different regions within the material that have a different polar axis. It is asymmetrical because there is no point at which the crystal could be cut that would leave the two remaining pieces with the same resultant polar axis.

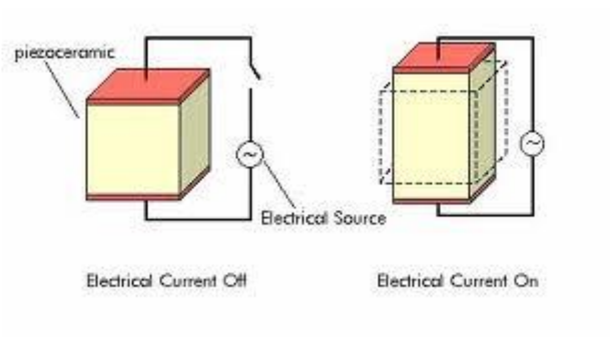

Figure 4.Piezoelectric Effect

The piezoelectric crystal bends in different ways at different frequencies. This bending is called the vibration mode. The crystal can be made into various shapes to achieve different vibration modes. To realize small, cost effective, and high performance products, several modes have been developed to operate over several frequency ranges. These modes allow us to make products working in the low kHz range up to the MHz range.

Different modes of operation

Based on geometrical configuration, logically there exist two types of deformation or effects. They are denoted as d31 and d33 mode. There are several applicable methods to improve the harvested power of MEMS micro generators, the proper coupling mode of operation is one the best method for to improve power harvesting. Then practically there are two modes of operation, the first mode called 31mode, in which the excited vibration force is applied perpendicular to the poling direction or pending beam, while the other is called 33mode, in which the force is applied on the same as the poling direction. Here analysis is done on d31 mode, as force applied to cantilever beam is perpendicular.

3.4 MATERIALS USED

Silicon

Silicon is the material used to create most integrated circuits used in consumer electronics in the modern industry. The economies of scale, ready availability of cheap high-quality materials and ability to incorporate electronic functionality make silicon attractive for a wide variety of MEMS applications. Silicon also has significant advantages engendered through its material properties. In single crystal form, silicon is an almost perfect Hookean material, meaning that when it is flexed there is virtually no hysteresis and hence almost no energy dissipation. As well as making for highly repeatable motion, this also makes silicon very reliable as it suffers very little fatigue and can have service lifetimes in the range of billions to trillions of cycles without breaking.

Silicon Wafers

Silicon wafers are a key component of integrated circuits such as those used to power computers, cell phones, and a wide variety of other devices. A silicon wafer consists of a thin slice of silicon which can be treated in various ways, depending on the type of electronics it is being used in. Silicon is a very high quality semiconductor, making it ideal for the production of such circuits, although other materials have been explored historically.

Lead Zirconium Titanate

Lead zirconium titanate is an inter metallic inorganic compound. Also called PZT, it is a ceramic material that shows a marked piezoelectric effect which finds practical applications in the area of electro ceramics .It is a white solid that is insoluble in all solvents.

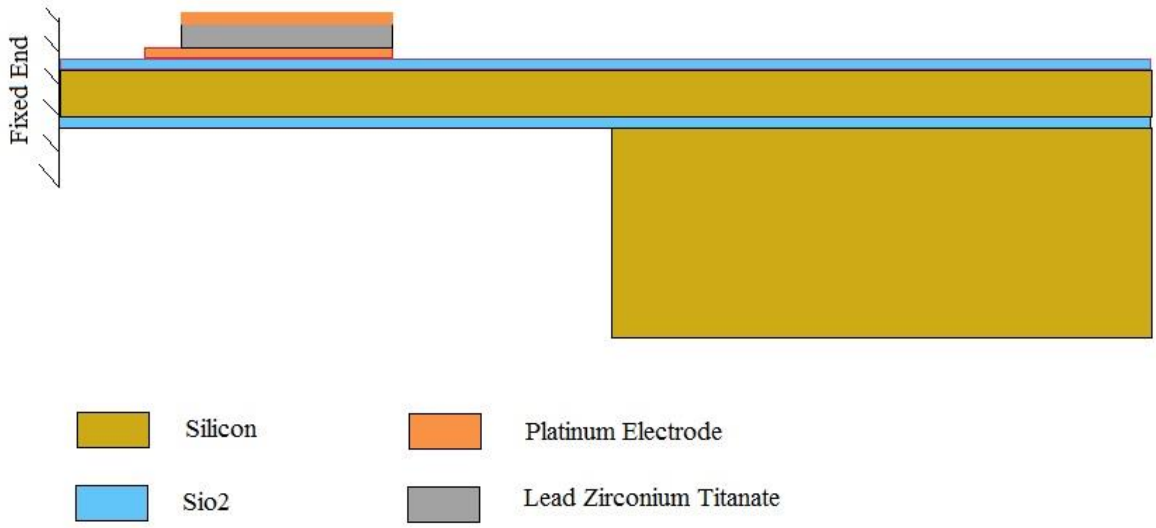

Figure 5.Proposed MEMS Structure

3.5 Analysis

The application of the force on the cantilever beam (one end of the beam fixed shown in figure 5) is implemented with a help of a vibrating medium. As the beam vibrates, the piezoelectric crystal fixed on the beam gets disturbed and hence a phenomenon called piezoelectric effect takes place i.e. conversion of force into electrical energy or vice versa. Thus different amount of force is applied (0.01mN, 0.001mN, 0.005mN) and their corresponding frequency, displacement and generation of voltage is determined.

CHAPTER 4

APPENDIX

Modelling Instructions

4.1 GLOBAL DEFENITION

Model Wizard

1 Go to the Model Wizard window.

2 Click Next.

.3 In the Add physics tree, select Structural Mechanics>Piezoelectric Devices (PZT).

4 Click Next.

5 Find the Studies subsection. In the tree, select Preset Studies>Frequency domain.

6 Click Finish.

Parameters

1 In the Model Builder window, right-click Global Definitions and choose Parameters.

2 In the Parameters settings window, locate the Parameters section.

3 In the table enter the following values.

Name	Expression	Description
L1	2000[μm]	Length of the silicon
T1	8[μm]	Thickness of the silicon
L2	2000[μm]	Length of the sio2
T2	0.5[μm]	Thickness of the sio2
L3	1000[μm]	Length of the silicon (mass)
T3	300[μm]	Thickness of the silicon(mass)
L4	500[μm]	Length of the Platinum electrode 1

T4	0.3[µm]	Thickness of the Platinum electrode 1
L5	400[µm]	Length of the Platinum electrode 2
T5	0.3[µm]	Thickness of the Platinum electrode 2
L6	400[µm]	Length of the Piezoelectric material
T6	1[µm]	Thickness of the Piezoelectric material
W	800[µm]	Width of the system

Table 2.Parameters

4.2 MODEL

Geometry 1

1 In the Model Builder window, under Model 1 click Geometry 1.

2 In the Geometry settings window, locate the Units section.

3 From the Length unit list, choose µm.

Units

Length unit	µm
Angular unit	Deg

Geometry statistics

Property	Value
Space dimension	3
Number of domains	8
Number of boundaries	45
Number of edges	80
Number of vertices	44

Table 3.Geometry statistics

Work Plane 1

Right-click Model 1>Geometry 1 and choose Work Plane.

Rectangle 1

1 In the Model Builder window, under Model 1>Geometry 1>Work Plane 1 right-click Plane Geometry and choose Rectangle.

2 In the Rectangle settings window, locate the Size section.

3 In the Width edit field, type 2000.

4 In the Height edit field, type 800.

5 Click the Build Selected button.

6 Click the Zoom Extents button on the Graphics toolbar.

Extrude 1

1 In the Model Builder window, under Model 1>Geometry 1 right-click Work Plane 1 and choose Extrude.

2 Select the object wp1.r1 only.

3 In the Extrude settings window, locate the Distances from Plane section.

4 In the table, enter the following settings:

Distance (µm) = 8

5 Click the Build Selected button.

Work Plane 2

Right-click Model 1>Geometry 1 and choose Work Plane.

Rectangle 2

1 In the Model Builder window, under Model 1>Geometry 1>Work Plane 2 right-click Plane Geometry and choose Rectangle.

2 In the Rectangle settings window, locate the Size section.

3 In the Width edit field, type 2000.

4 In the Height edit field, type 800.

5 Click the Build Selected button.

6 Click the Zoom Extents button on the Graphics toolbar.

Extrude 2

1 In the Model Builder window, under Model 1>Geometry 1 right-click Work Plane 2 and choose Extrude.

2 Select the object wp2.r2 only.

3 In the Extrude settings window, locate the Distances from Plane section.

4 In the table, enter the following settings:

Distance (µm) = 0.5

5 Click the Build Selected button.

Work Plane 3

Right-click Model 1>Geometry 1 and choose Work Plane.

Rectangle 3

1 In the Model Builder window, under Model 1>Geometry 1>Work Plane 3 right-click Plane Geometry and choose Rectangle.

2 In the Rectangle settings window, locate the Size section.

3 In the Width edit field, type 2000.

4 In the Height edit field, type 800.

5 Click the Build Selected button.

6 Click the Zoom Extents button on the Graphics toolbar.

Extrude 3

1 In the Model Builder window, under Model 1>Geometry 1 right-click Work Plane 3 and choose Extrude.

2 Select the object wp3.r3 only.

3 In the Extrude settings window, locate the Distances from Plane section.

4 In the table, enter the following settings:

Distance (µm) = -0.5

5 Click the Build Selected button.

Work Plane 4

Right-click Model 1>Geometry 1 and choose Work Plane.

Rectangle 4

1 In the Model Builder window, under Model 1>Geometry 1>Work Plane 4 right-click Plane Geometry and choose Rectangle.

2 In the Rectangle settings window, locate the Size section.

3 In the Width edit field, type 1000.

4 In the Height edit field, type 800.

5 Click the Build Selected button.

6 Click the Zoom Extents button on the Graphics toolbar.

Extrude 4

1 In the Model Builder window, under Model 1>Geometry 1 right-click Work Plane 4 and choose Extrude.

2 Select the object wp4.r4 only.

3 In the Extrude settings window, locate the Distances from Plane section.

4 In the table, enter the following settings:

Distance (µm) = 300

5 Click the Build Selected button.

Work Plane 5

Right-click Model 1>Geometry 1 and choose Work Plane.

Rectangle 5

1 In the Model Builder window, under Model 1>Geometry 1>Work Plane 5 right-click Plane Geometry and choose Rectangle.

2 In the Rectangle settings window, locate the Size section.

3 In the Width edit field, type 500.

4 In the Height edit field, type 800.

5 Click the Build Selected button.

6 Click the Zoom Extents button on the Graphics toolbar.

Extrude 5

1 In the Model Builder window, under Model 1>Geometry 1 right-click Work Plane 5 and choose Extrude.

2 Select the object wp5.r5 only.

3 In the Extrude settings window, locate the Distances from Plane section.

4 In the table, enter the following settings:

Distance (µm) = 0.3

5 Click the Build Selected button.

Work Plane 6

Right-click Model 1>Geometry 1 and choose Work Plane.

Rectangle 6

1 In the Model Builder window, under Model 1>Geometry 1>Work Plane 6 right-click Plane Geometry and choose Rectangle.

2 In the Rectangle settings window, locate the Size section.

3 In the Width edit field, type 400.

4 In the Height edit field, type 800.

5 Click the Build Selected button.

6 Click the Zoom Extents button on the Graphics toolbar.

Extrude 6

1 In the Model Builder window, under Model 1>Geometry 1 right-click Work Plane 6 and choose Extrude.

2 Select the object wp6.r6 only.

3 In the Extrude settings window, locate the Distances from Plane section.

4 In the table, enter the following settings:

Distance (µm) = 1

5 Click the Build Selected button.

Work Plane 7

Right-click Model 1>Geometry 1 and choose Work Plane.

Rectangle 7

1 In the Model Builder window, under Model 1>Geometry 1>Work Plane 7 right-click Plane Geometry and choose Rectangle.

2 In the Rectangle settings window, locate the Size section.

3 In the Width edit field, type 400.

4 In the Height edit field, type 800.

5 Click the Build Selected button.

6 Click the Zoom Extents button on the Graphics toolbar.

Extrude 7

1 In the Model Builder window, under Model 1>Geometry 1 right-click Work Plane 7 and choose Extrude.

2 Select the object wp7.r7 only.

3 In the Extrude settings window, locate the Distances from Plane section.

4 In the table, enter the following settings:

Distance (μm) = 0.3

5 Click the Build Selected button.

Form Union

1 In the Model Builder window, under Model 1>Geometry 1 click Form Union.

2 In the Finalize settings window, locate the Finalize section.

3 From the Finalization method list, choose Form an assembly.

4 Clear the Create pairs check box.

5 Click the Build Selected button.

6 Click the Go to Default 3D View button on the Graphics toolbar.

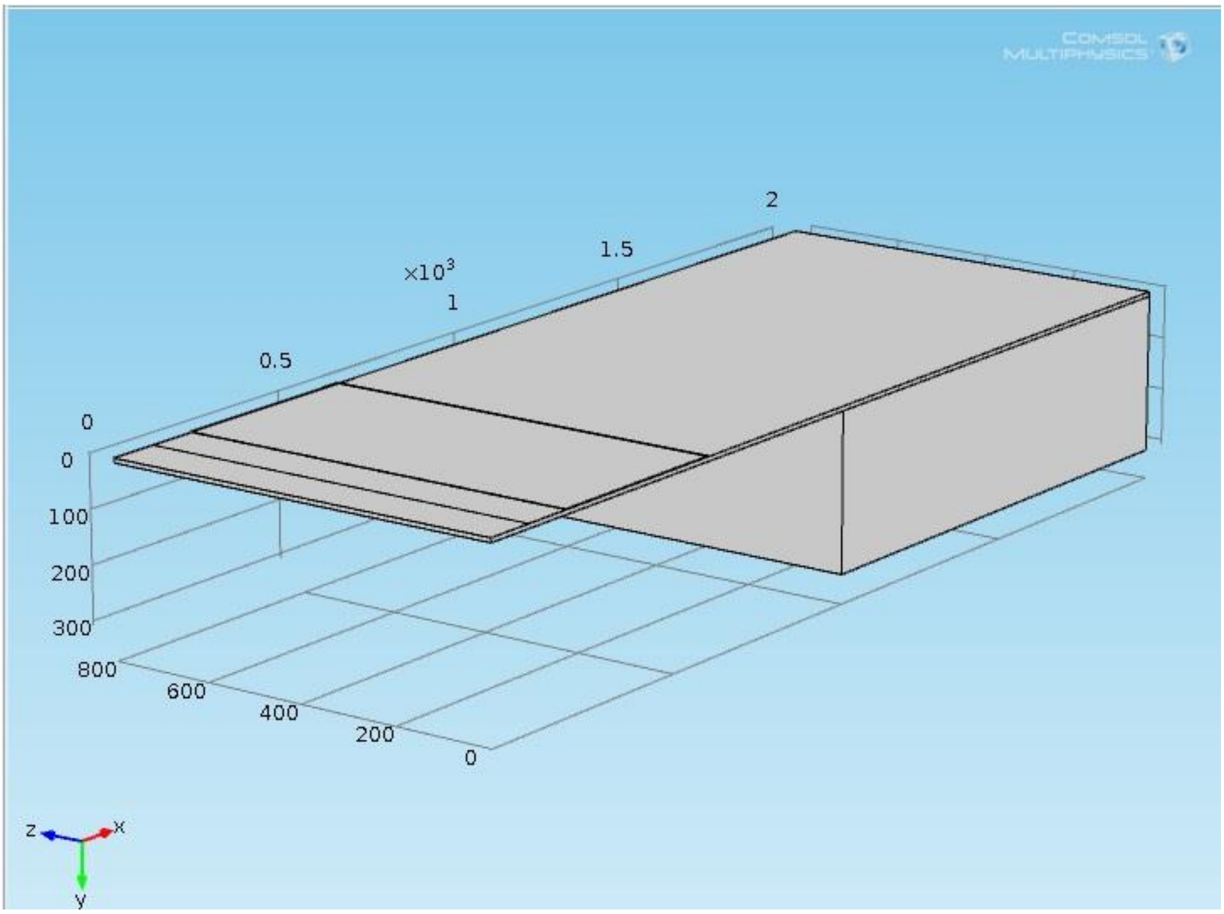

Figure 6.Model

4.3 MATERIALS

Silicon

For the Silicon layers, use a library material.

1 In the Model Builder window, under Model 1 right-click Materials and choose Open Material Browser.

2 In the Material Browser window, locate the Materials section.

3 In the tree, select MEMS>Semi conductor>Si.

4 Right-click and choose Add Material to Model from the menu.

5 In the Model Builder window, under Model 1>Materials click Si.

6 Select Domains 2 and 7 only.

For the foam core, specify the material properties by hand.

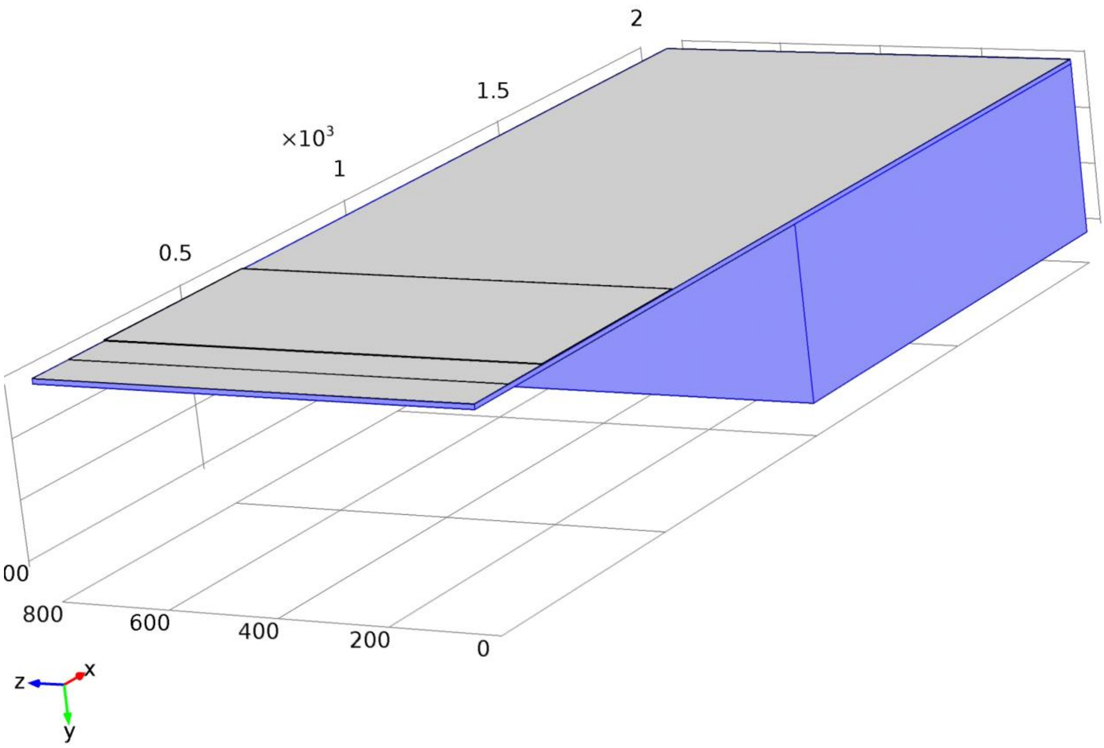

Figure 7.Silicon Material Selection

Selection

Geometric entity level	Domain
Selection	Domains 2, 7

Material parameters

Name	**Value**	**Unit**
Density	2329[kg/m^3]	kg/m^3
Young's modulus	170e9[Pa]	Pa
Poisson's ratio	0.28	1

Table 4.Material Property-Silicon

SiO_2

1 In the Model Builder window, right-click Materials and choose Open Material Browser.

2 In the Material Browser window, locate the Materials section.

3 In the tree, select MEMS>Insulators>SiO_2.

4 Right-click and choose Add Material to Model from the menu.

5 In the Model Builder window, under Model 1>Materials click SiO_2.

6 Select Domains 1, 3 and 8 only.

For the foam core, specify the material properties by hand.

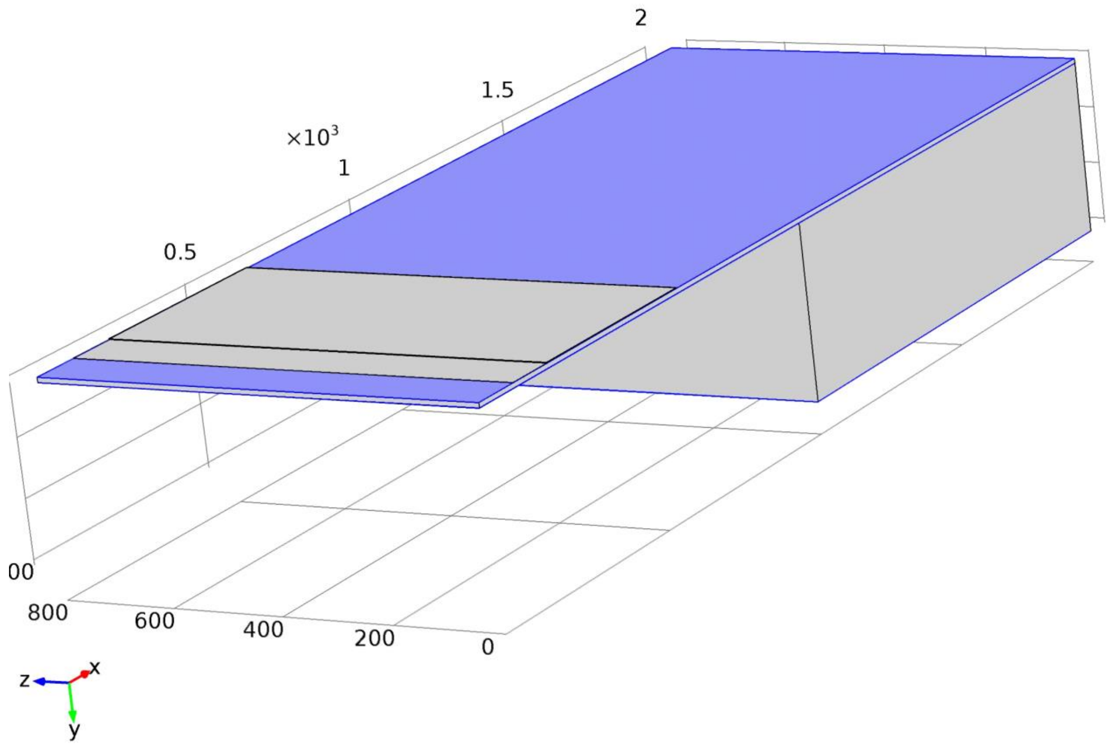

Figure 8.SiO_2 Material Selection

Selection

Geometric entity level	Domain
Selection	Domains 1, 3, 8

Material parameters

Name	Value	Unit
Density	2200[kg/m^3]	kg/m^3
Young's modulus	70e9[Pa]	Pa
Poisson's ratio	0.17	1

Table 5.Material Property-Sio$_2$

Platinum

1 In the Model Builder window, right-click Materials and choose Open Material Browser.

2 In the Material Browser window, locate the Materials section.

3 In the tree, select MEMS>Metal>Pt.

4 Right-click and choose Add Material to Model from the menu.

5 In the Model Builder window, under Model 1>Materials click Pt.

6 Select Domains 4 and 5 only.

For the foam core, specify the material properties by hand.

Selection

Geometric entity level	Domain
Selection	Domains 4–5

Material parameters

Name	Value	Unit
Young's modulus	168e9	Pa
Poisson's ratio	0.38	1
Density	21450	kg/m^3

Table 6.Material Property-Platinum

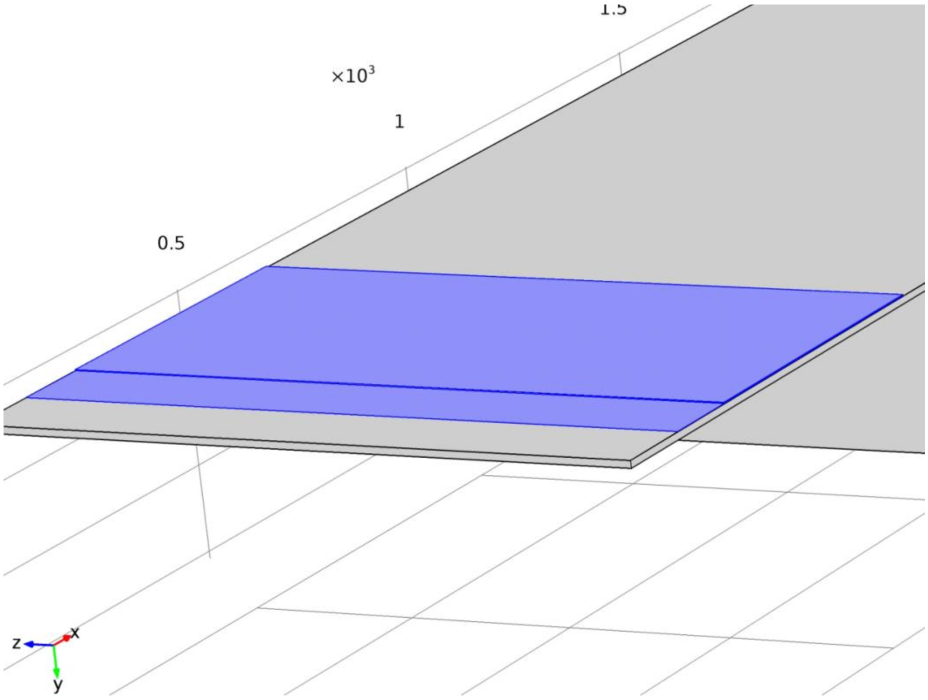

Figure 9.Platinum Material Selection

Lead Zirconate Titanate (PZT-5A)

1 In the Model Builder window, right-click Materials and choose Open Material Browser.

2 In the Material Browser window, locate the Materials section.

3 In the tree, select Piezoelectric>Lead Zirconate Titanate (PZT-5A).

4 Right-click and choose Add Material to Model from the menu.

5 In the Model Builder window, under Model 1>Materials click Lead Zirconate Titanate (PZT-5A).

6 Select Domain 6 only.

Selection

Geometric entity level	Domain
Selection	Domain 6

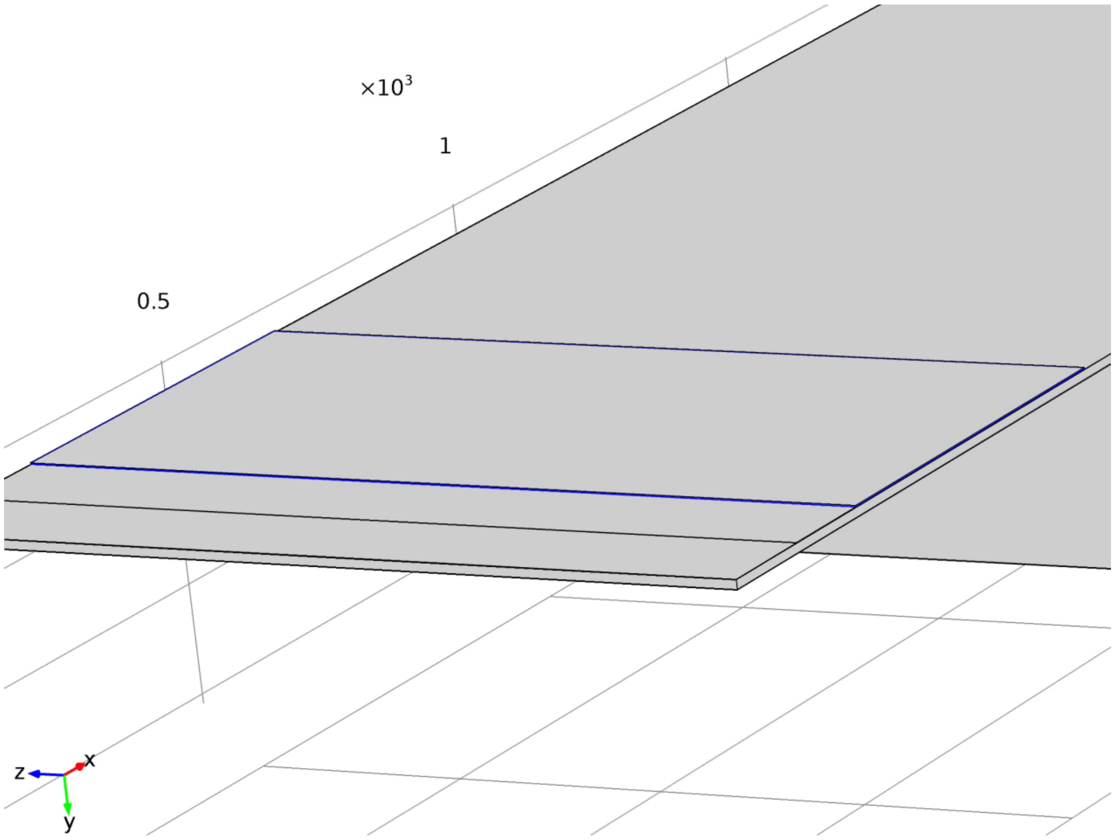

Figure 10.Lead ZirconateTitanate Material Selection

Material parameters

Name	**Value**	**Unit**
Density	7750[kg/m^3]	kg/m^3
Elasticity matrix (Ordering: xx, yy, zz, yz, xz, xy)	{1.20346e011[Pa], 7.51791e010[Pa], 1.20346e011[Pa], 7.50901e010[Pa], 7.50901e010[Pa], 1.10867e011[Pa], 0[Pa], 0[Pa], 0[Pa], 2.10526e010[Pa], 0[Pa], 0[Pa], 0[Pa], 0[Pa], 2.10526e010[Pa], 0[Pa], 0[Pa], 0[Pa], 0[Pa], 0[Pa], 2.25734e010[Pa]}	Pa

Coupling matrix	{0[C/m^2], 0[C/m^2], 5.35116[C/m^2], 0[C/m^2], 0[C/m^2], 5.35116[C/m^2], 0[C/m^2], 0[C/m^2], 15.7835[C/m^2], 0[C/m^2], 12.2947[C/m^2], 0[C/m^2], 12.2947[C/m^2], 0[C/m^2], 0[C/m^2], 0[C/m^2], 0[C/m^2], 0[C/m^2]}	C/m^2
Relative permittivity	{919.1, 919.1, 826.6}	1

Table 7.Material Property-Lead Zirconate Titanate

4.4 PIEZOELECTRIC DEVICES

Piezoelectric Material 1

1 In the Model Builder window, expand the Model 1>Piezoelectric Devices node, then click Piezoelectric Material 1.

2 In the Piezoelectric Material settings window, locate the Coordinate System Selection section.

3 From the Coordinate system list, choose Base Vector System 2.

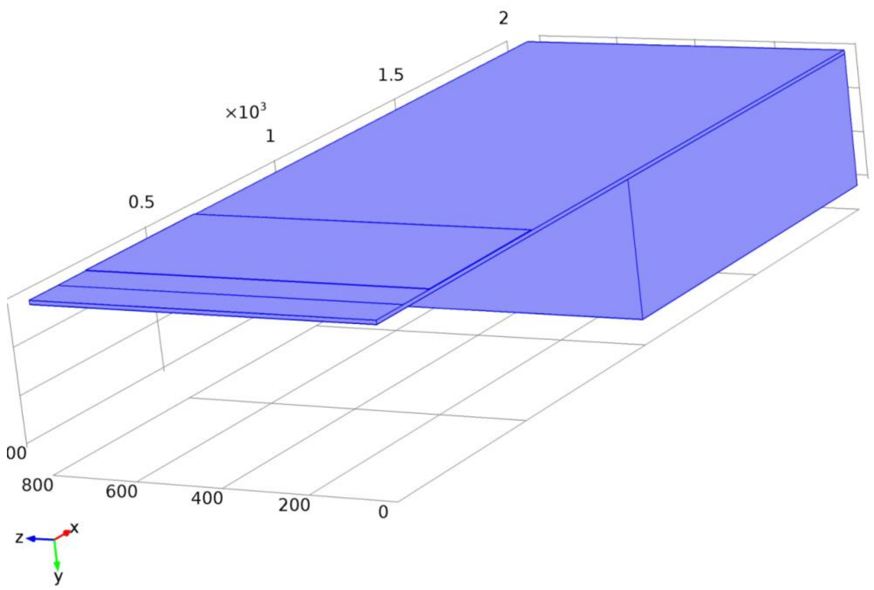

Figure 11.Piezoelectric Device

Selection

Geometric entity level	Domain
Selection	Domains 1–8

Equations

$$-\nabla \cdot \sigma = \mathbf{F}_V$$

$$\nabla \cdot \mathbf{D} = \rho_V$$

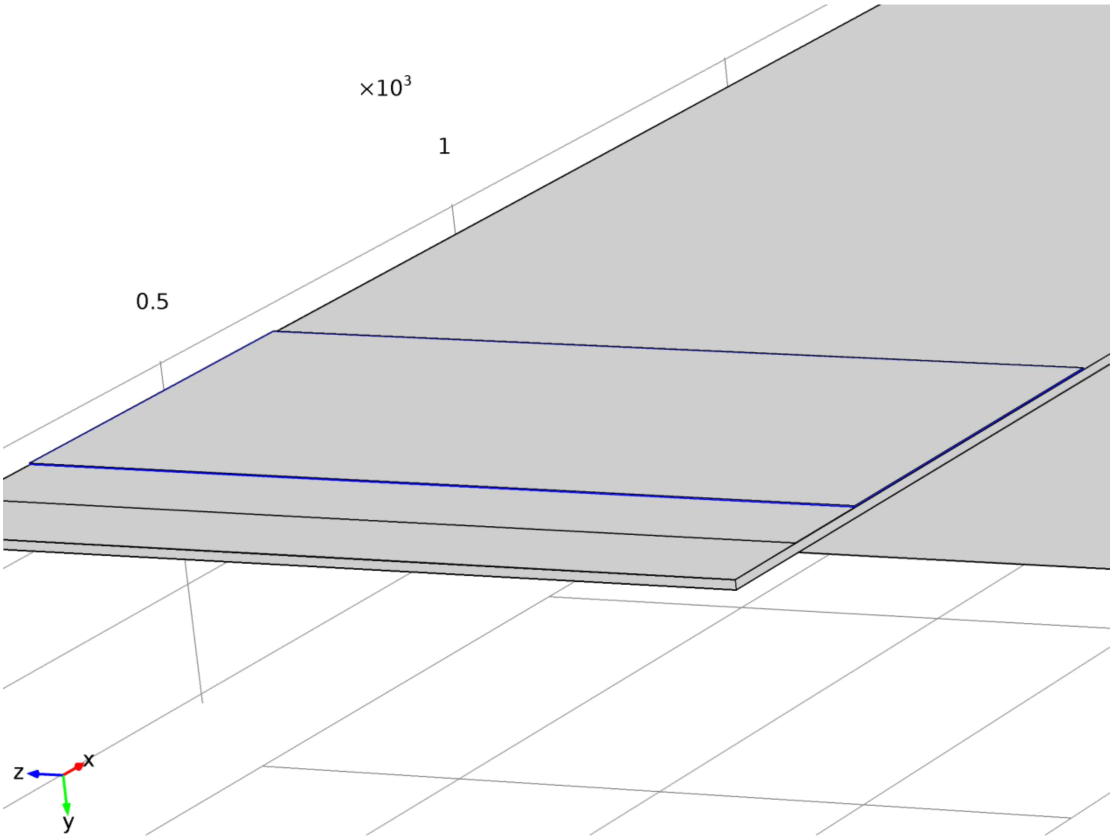

Figure 12.Piezoelectric Meterial selection

Selection

Geometric entity level	Domain
Selection	Domain 6

Linear Elastic Material 1

1 In the Model Builder window, right-click Piezoelectric Devices and choose the domain setting Linear Elastic Material.

2 Select Domains 1–5, 7 and 8 only.

Selection

Geometric entity level	Domain
Selection	Domains 1–5, 7–8

Fixed Constraint

1 In the Model Builder window, right-click Piezoelectric Devices and choose the boundary condition Structural>Fixed Constraint.

2 Select Boundaries 1, 5, and 9 only.

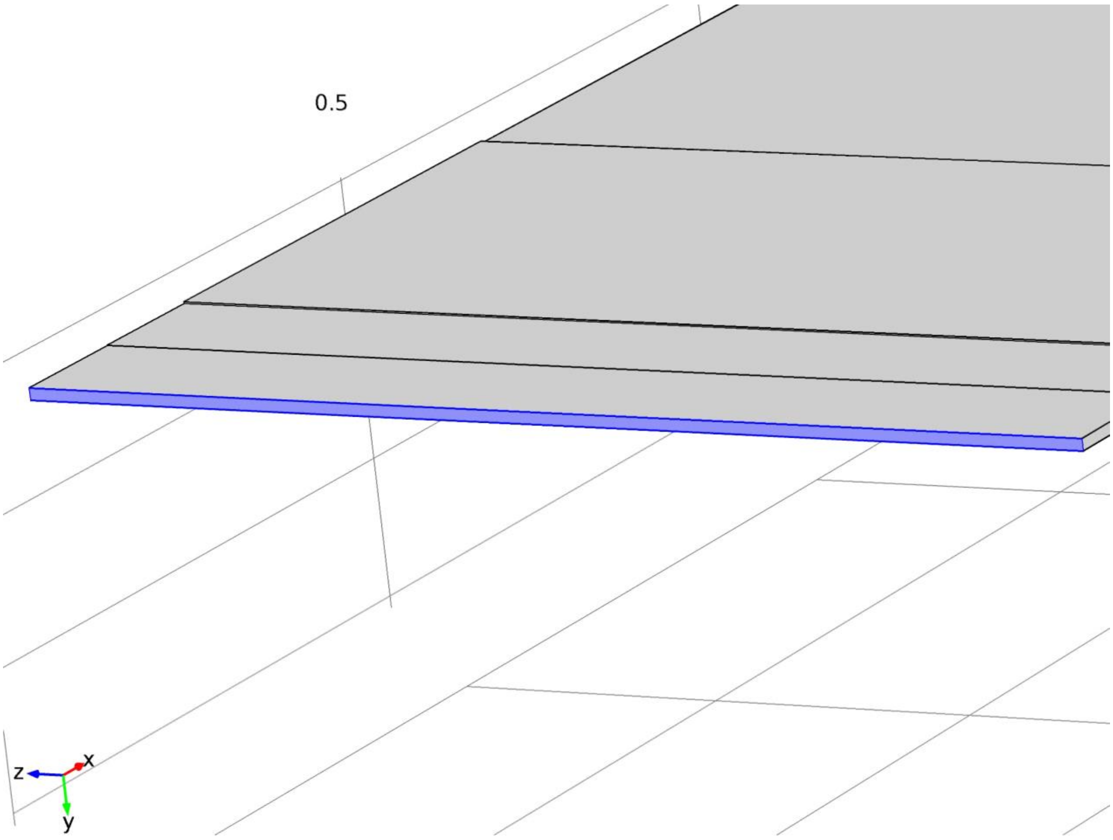

Figure 13.Fixed Constraint

Selection

Geometric entity level	Boundary
Selection	Boundaries 1, 5, 9

Free

1 In the Model Builder window, right-click Piezoelectric Devices and choose the boundary condition Structural>Free.

2 Select Boundaries 2–4, 7–8, 11–12, 14–17, 19–23, 25–26, 28–32, 34–36, 38–45only.

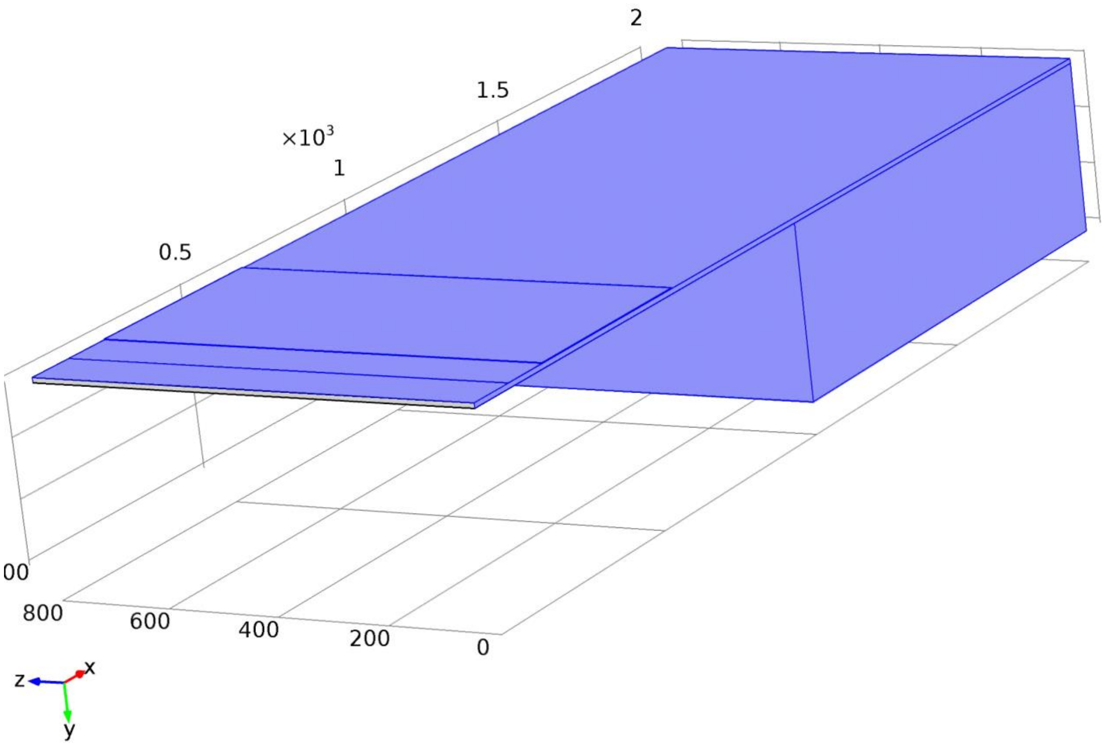

Figure 14.Free Constraint

Selection

Geometric entity level	Boundary
Selection	Boundaries 2–4, 7–8, 11–12, 14–17, 19–23, 25–26, 28–32, 34–36, 38–45

Initial Values

1 In the Model Builder window, right-click Piezoelectric Devices and choose the Domain setting Initial Values.

2 Select Domain 1–8only.

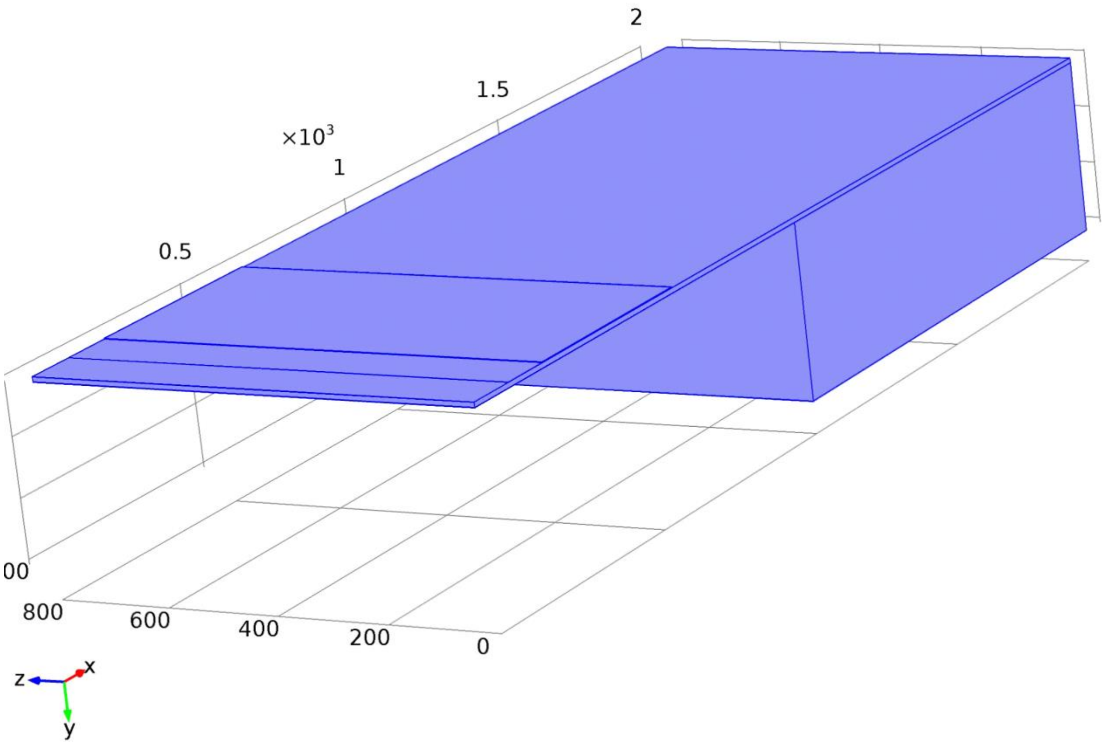

Figure 15.Initial Values

Selection

Geometric entity level	Domain
Selection	Domains 1–8

Body Load

1 In the Model Builder window, right-click Piezoelectric Devices and choose the body condition Structural>Body Load.

2 Select Domain 7 only.

3 Density of the Body is act on the Y direction.

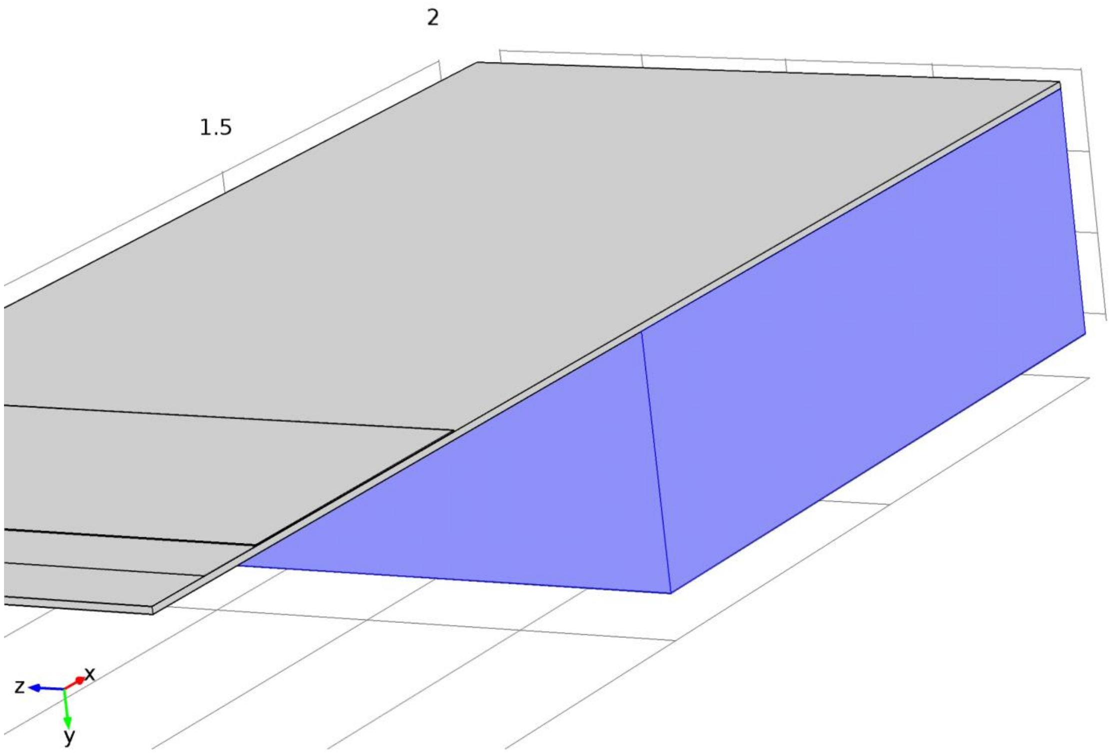

Figure 16.Body Load

Selection

Geometric entity level	Domain
Selection	Domain 7

Equations

Settings

Description	**Value**
Body load	{0, 2329*9.81, 0}

Boundary Load

1 In the Model Builder window, right-click Piezoelectric Devices and choose the boundary condition Structural>Boundary Load.

2 Select Boundary 13 only.

3 Then apply the force in Y direction 0.001mN.

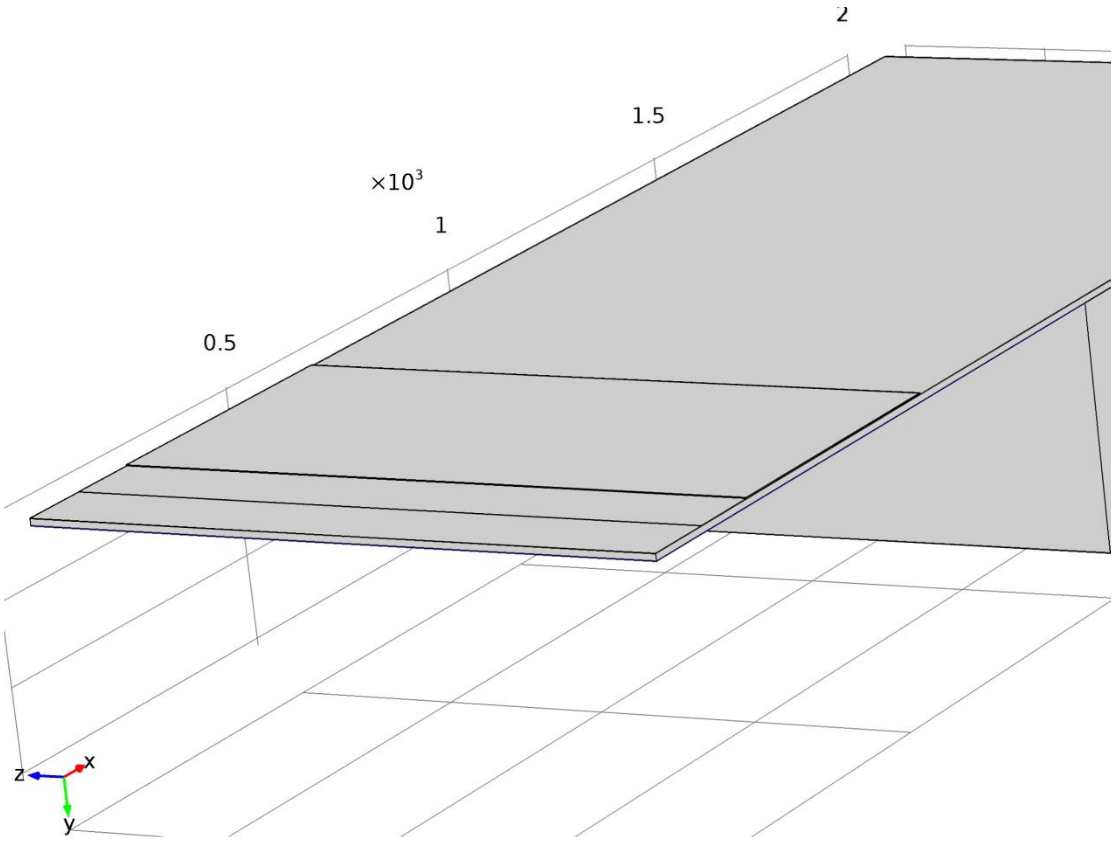

Figure 17.Boundary Load

Selection

Geometric entity level	Boundary
Selection	Boundary 13

Equations

Description	**Value**
Load type	Total force
Total force	{0, 0.000001, 0}

4.5 MESH

Free Tetrahedral 1

1 In the Model Builder window, under Model 1 right-click Mesh 1 and choose Free Tetrahedral.

2 In the Settings window, click Build All.

Mesh statistics

Property	Value
Minimum element quality	1.511E8
Average element quality	0.286
Tetrahedral elements	69680
Triangular elements	26049
Edge elements	2061
Vertex elements	44

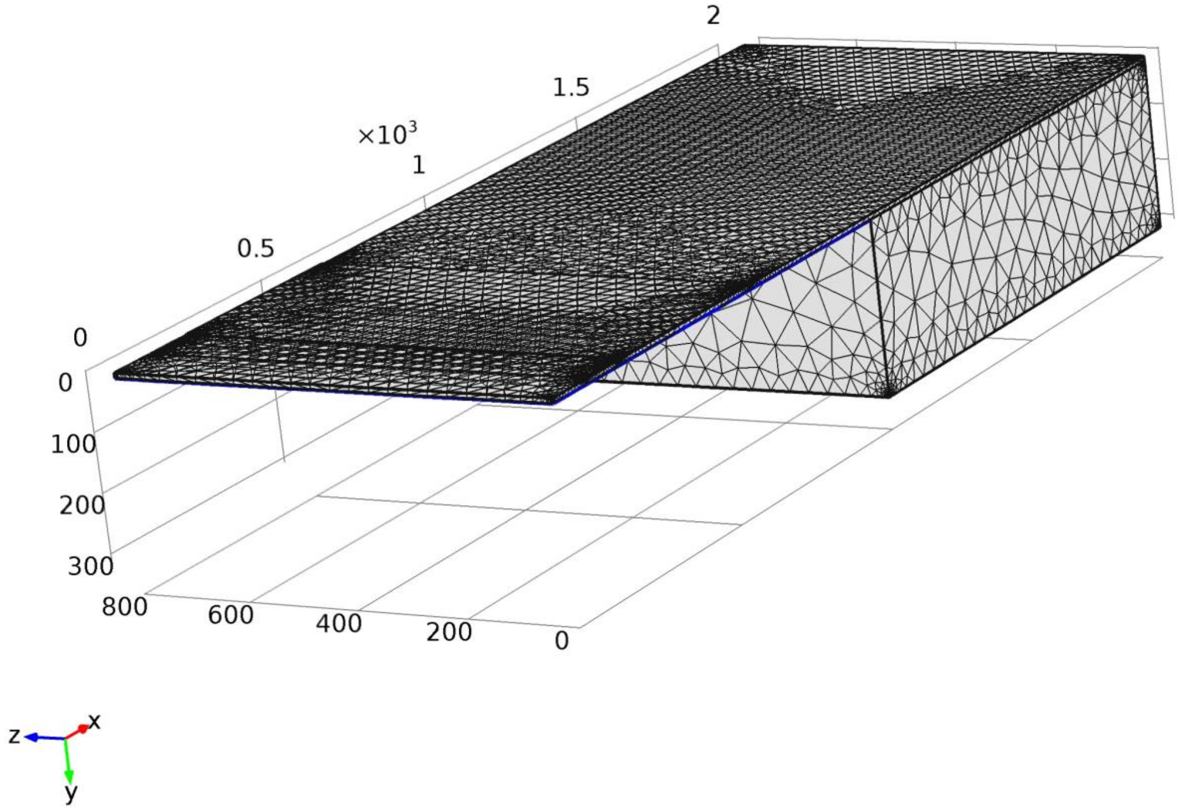

Figure 18.Meshing

Size (size)

Settings

Name	**Value**
Maximum element size	200
Minimum element size	36
Resolution of curvature	0.6
Resolution of narrow regions	0.5
Maximum element growth rate	1.5

4.6 STUDY

Frequency Domain

1 In the Model Builder window, right-click Study 2 and choose Study Steps>Frequency Domain.

2 In the Frequency Domain settings window, locate the Physics and Variables Selection section.

3 In the table, enter the following settings:

4 Locate the Study Settings section. Click the Range button.

5 Go to the Range dialog box.

6 In the Start edit field, type 1.

7 In the Step edit field, type 1000.

8 In the Stop edit field, type 10000.

9 Click the Replace button.

10 Right-click Study 1 and choose Compute.

4.7 RESULTS

4.7.1 Data sets

Displacement (µm)

1 In the Model Builder window, under Results>Displacement (pzd) click Surface.

2 In the Surface settings window, click Replace Expression in the upper-right corner of the Expression section. From the menu, choose Piezoelectric Devices (Solid Mechanics)>Displacement>Displacement field (Material)>Total Displacement.

3 Locate the Expression section. From the Unit list, choose µm.

4 Click the Plot button.

5 Click the Zoom Extents button on the Graphics toolbar.

6 Click the Scene Light button on the Graphics toolbar.

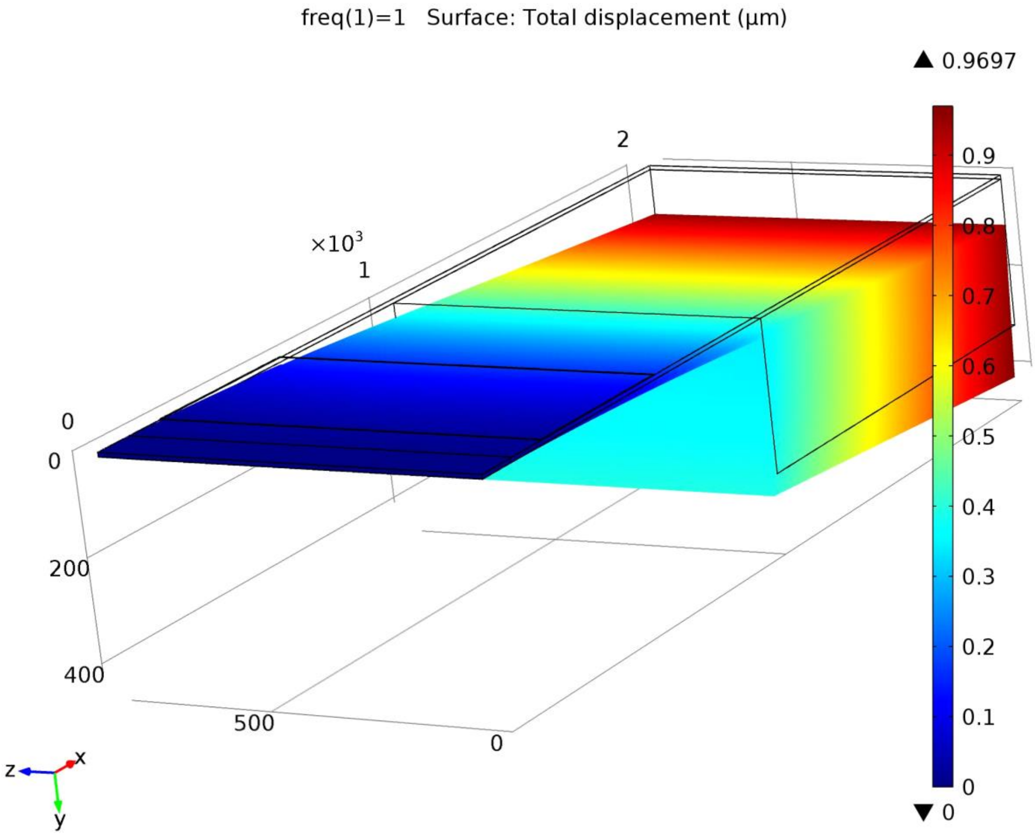

Figure 19.Displacement

freq (1)=1 Surface: Total displacement (µm)

Electric Potential (V)

1 In the Model Builder window, under Results>Potential (pzd) click Surface 1.

2 In the Surface settings window, locate the Plane Data section.

3 From the Plane list, choose yz-planes.

4 Click the Plot button.

5 Click the Zoom In button on the Graphics toolbar.

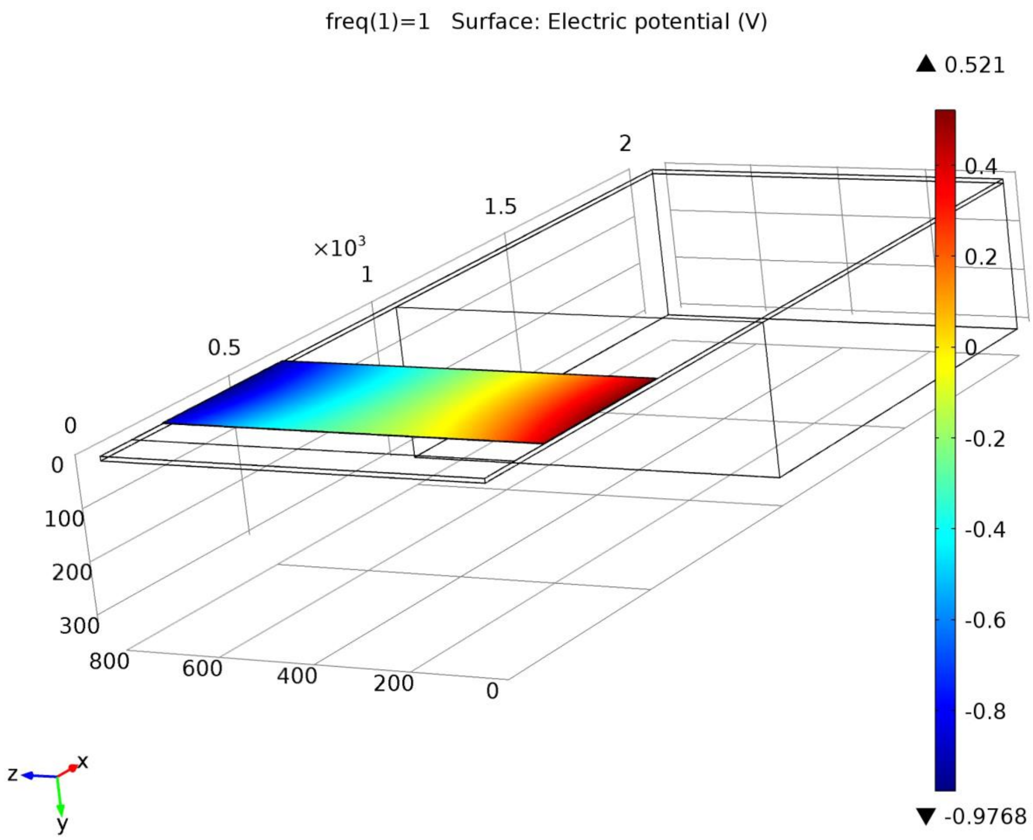

Figure 20.Electric Potential

freq(1)=1 Surface: Electric potential (V)

Stress (N/m^2)

1 In the Model Builder window, under Results>3D Plot Group.

2 Then Renamed > click Surface

2 In the Surface settings window, click Replace Expression in the upper-right corner of the Expression section. From the menu, choose Piezoelectric Devices (Solid Mechanics)>Stress>Von mises Stress (Pzt.mises).

3 Locate the Expression section. From the Unit list, choose N/m^2.

4 Click the Plot button.

5 Click the Zoom Extents button on the Graphics toolbar.

6 Click the Scene Light button on the Graphics toolbar.

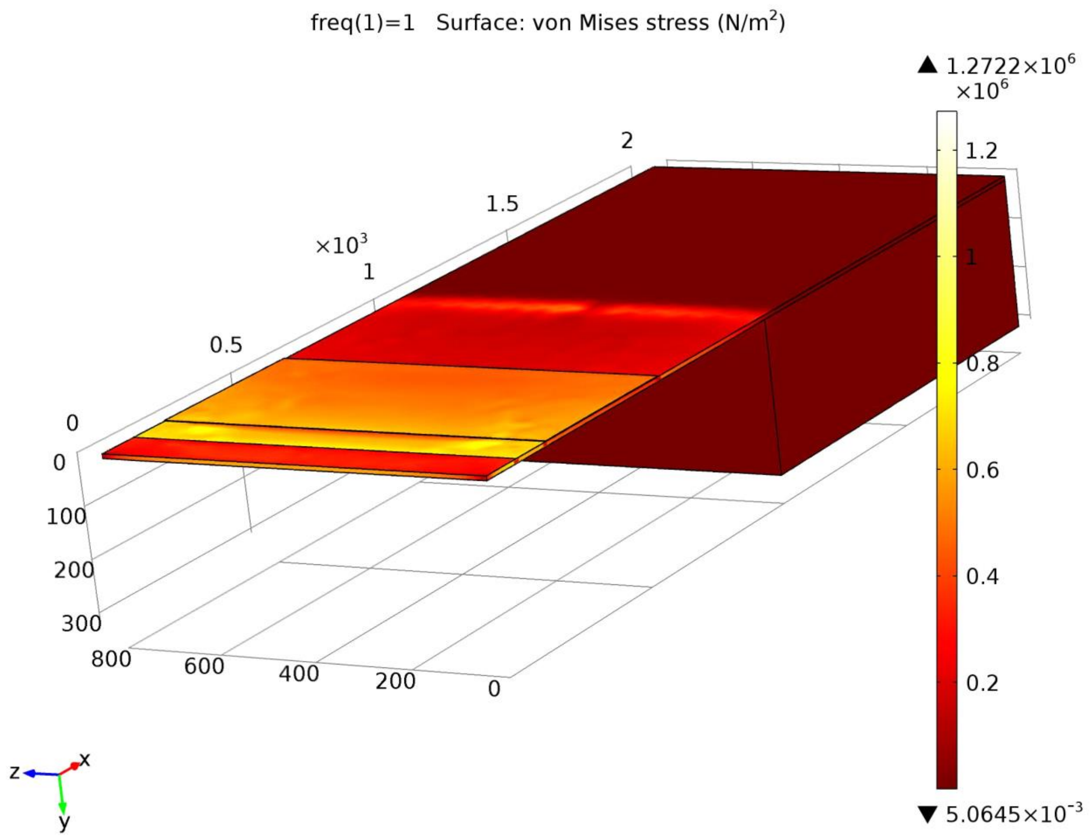

Figure 21.Stress

freq(1)=1 Surface: von Mises stress (N/m^2)

4.7.2Plot Group

Displacement

1 In the Model Builder window, right-click Results and choose 1D Plot Group.

2 Right-click 1D Plot Group 1 and choose Line Graph.

3 Select Boundary 13 only.

4 In the Line Graph settings window, click Replace Expression in the upper-right corner of the y-Axis Data section. From the menu, choose Piezoelectric Devices (Solid Mechanics)>Displacement>Displacement field (Material)>Total Displacement.

5 Locate the Expression section. From the Unit list, choose µm.

6 In the Line Graph settings window, locate the X-Axis Data section as Frequency.

7 Then plot the graph.

8 In the Graphics window shows the graph between Frequency &Displacement.

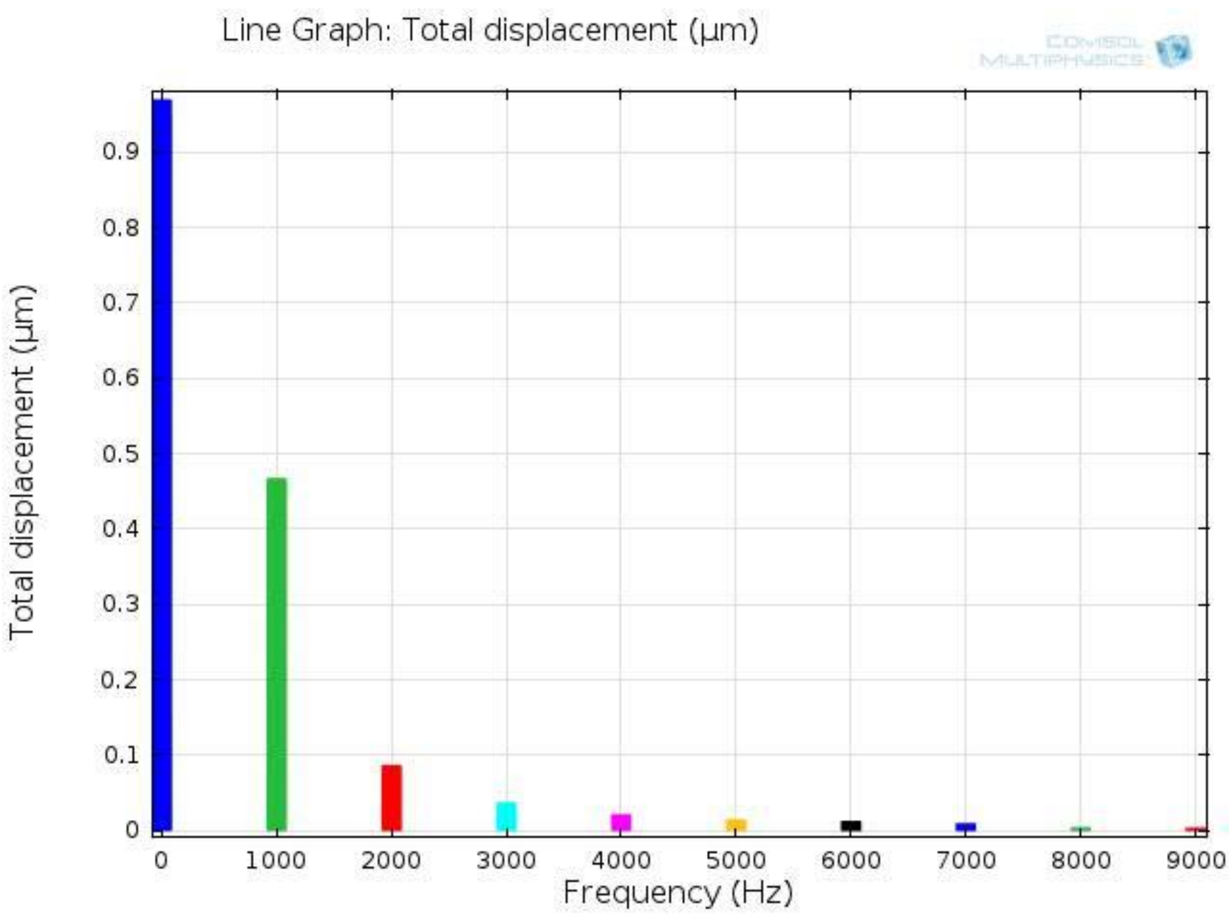

Figure 22.Plot Group - Displacement

Electric Potential

1 In the Model Builder window, right-click Results and choose 1D Plot Group.

2 Right-click 1D Plot Group 1 and choose Line Graph.

3 Select Boundary 33 only.

4 In the Line Graph settings window, click Replace Expression in the upper-right corner of the y-Axis Data section. From the menu, choose Piezoelectric Devices (Electrical Qusistatics)>Electrical>Electric Potential.

5 In the Line Graph settings window, locate the X-Axis Data section as Frequency.

6 Then plot the graph.

7 In the Graphics window shows the graph between Frequency and Electric Potential.

Frequency (Hz) Vs Electric potential (V)

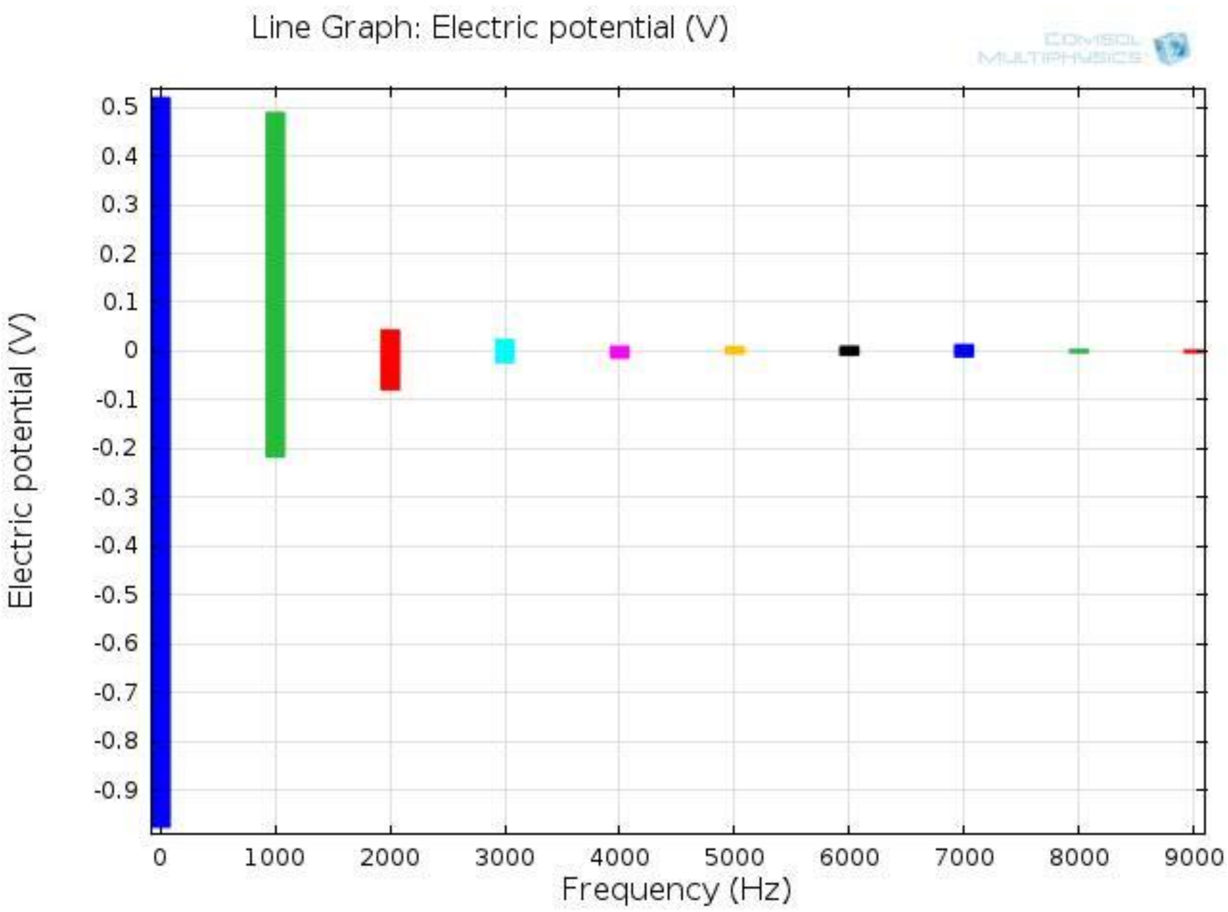

Figure 23.Plot Group – Electric Potential

Stress

1 In the Model Builder window, right-click Results and choose 1D Plot Group.

2 Right-click 1D Plot Group 1 and choose Line Graph.

3 Select Boundary 13 only.

4 In the Line Graph settings window, click Replace Expression in the upper-right corner of the y-Axis Data section. From the menu, choose Piezoelectric Devices (Solid Mechanics)>Stress>Von mises Stress (Pzt.mises).

5 Locate the Expression section. From the Unit list, choose N/m^2.6 In the Line Graph settings window, locate the X-Axis Data section as Frequency.

6 Then plot the graph.

7 In the Graphics window shows the graph between Frequency and Stress.

Frequency (Hz) Vs Stress (N/m2)

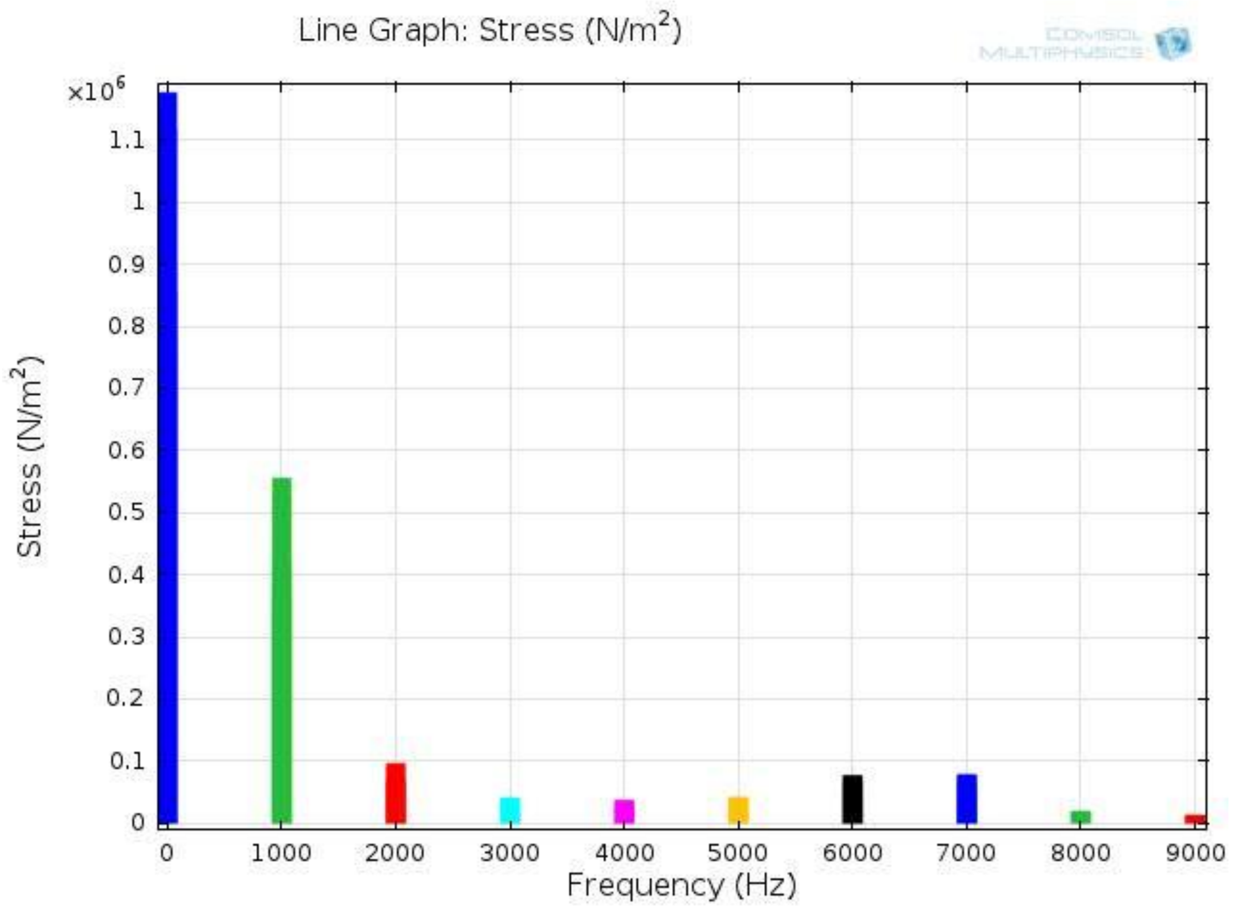

Figure 24.Plot Group - Stress

CHAPTER-5

RESULT

5.1 TABULATION

Applied Force - 0.001mN

On application of 0.001mN, the corresponding frequency, displacement, stress and voltage generated is tabulated below.

Frequency (Hz)	Displacement (μm)	Electric Potential (V)	Stress(N/m^2)*10^5
1	0.6661	0.4228	7.6988
1001	0.3028	0.1488	4.9665
2001	0.0456	0.0487	2.2941
3001	0.0299	0.0521	2.3371
4001	0.0328	0.0686	2.6522
5001	0.0453	0.0865	4.2125
6001	0.1052	0.205	11.473
7001	0.148	0.2481	18.791
8001	0.0376	0.0719	5.5238
9001	0.0201	0.0533	3.389

Table 8. 0.001mN Force applied

Applied Force - 0.0001mN

On application of 0.0001mN, the corresponding frequency, displacement, stress and voltage generated is tabulated below

Frequency (Hz)	Displacement (μm)	Electric Potential (V)	Stress(N/m^2)*10^5
1	0.9697	0.541	12.722
1001	0.4669	0.49	6.0083
2001	0.0864	0.0441	1.0428
3001	0.0371	0.0247	0.4217
4001	0.021	0.0106	0.3665
5001	0.0141	0.0101	0.4066
6001	0.0122	0.0106	0.7359
7001	0.0090	0.0143	0.7410
8001	0.0037	0.0039	0.2273
9001	0.0032	0.0026	0.1672

Table 9. 0.0001mN Force applied

Applied Force - 0.0005mN

On application of 0.0005mN, the corresponding frequency, displacement and the voltage generated is tabulated below

Frequency (Hz)	Displacement (μm)	Electric Potential (V)	Stress(N/m^2)*10^5
1	0.8347	0.5333	10.489
1001	0.3939	0.2889	5.5445
2001	0.0681	0.0502	1.3826
3001	0.0252	0.0273	1.1341
4001	0.0168	0.0226	1.2242
5001	0.0208	0.0355	1.6463
6001	0.0452	0.0743	4.6903
7001	0.0608	0.1005	7.9401
8001	0.0157	0.0318	2.3953
9001	0.0095	0.0192	1.5009

Table 10. 0.0005mN Force applied

5.2GRAPH

5.2.1 Displacement Vs Frequency

The frequency vs displacement graph on application of three different loads such as 0.001mN, 0.0001mN, 0.0005mN is given below

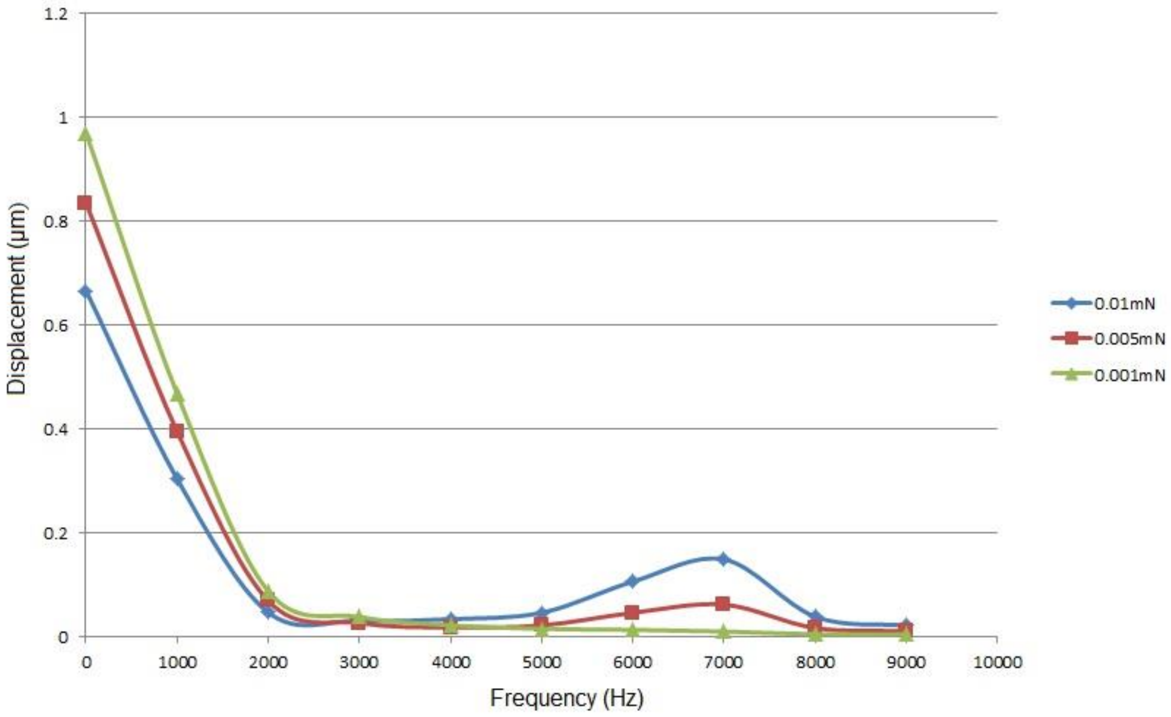

Figure 25. Displacement Vs Frequency

5.2.2 Electric potential Vs Frequency

The frequency vs electric potential on application of three different loads such as 0.001mN, 0.0001mN, 0.0005mN is given below

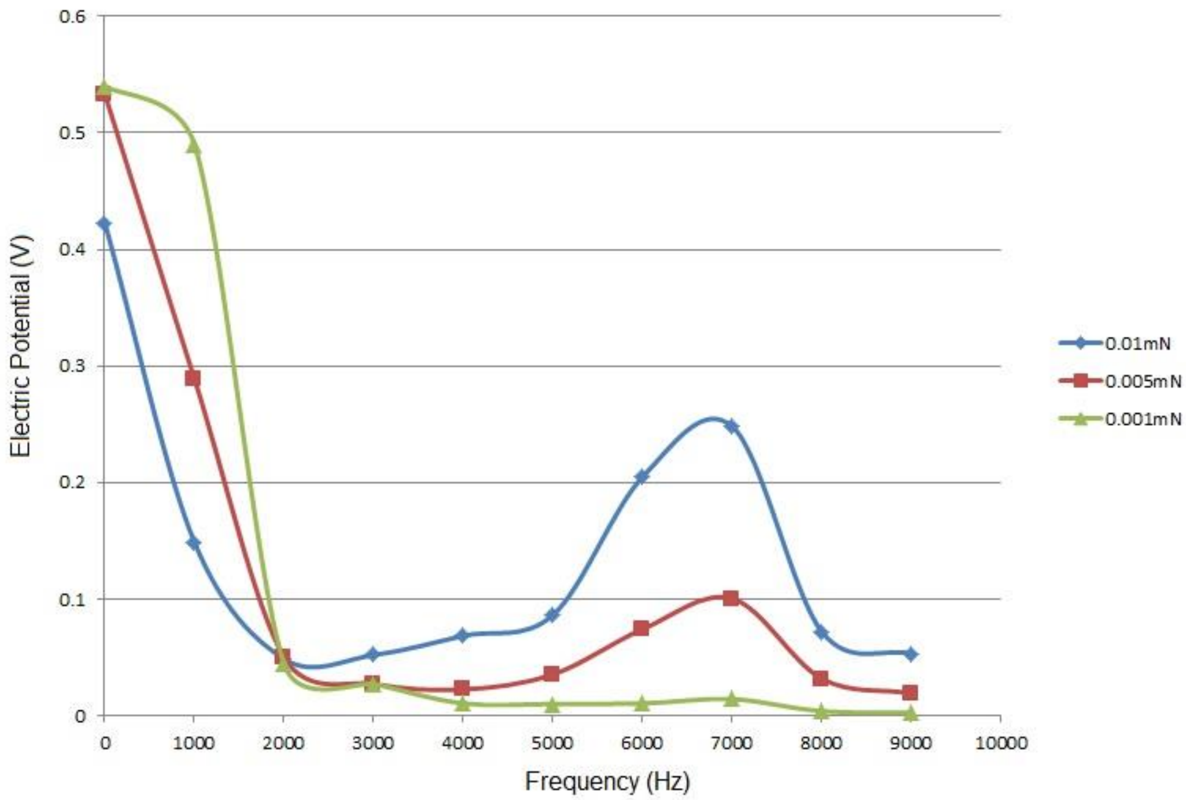

Figure 26.Electric potential Vs Frequency

5.2.3 Stress Vs Frequency

The frequency vs stress on application of three different loads such as 0.001mN, 0.0001mN, 0.0005mN is given below

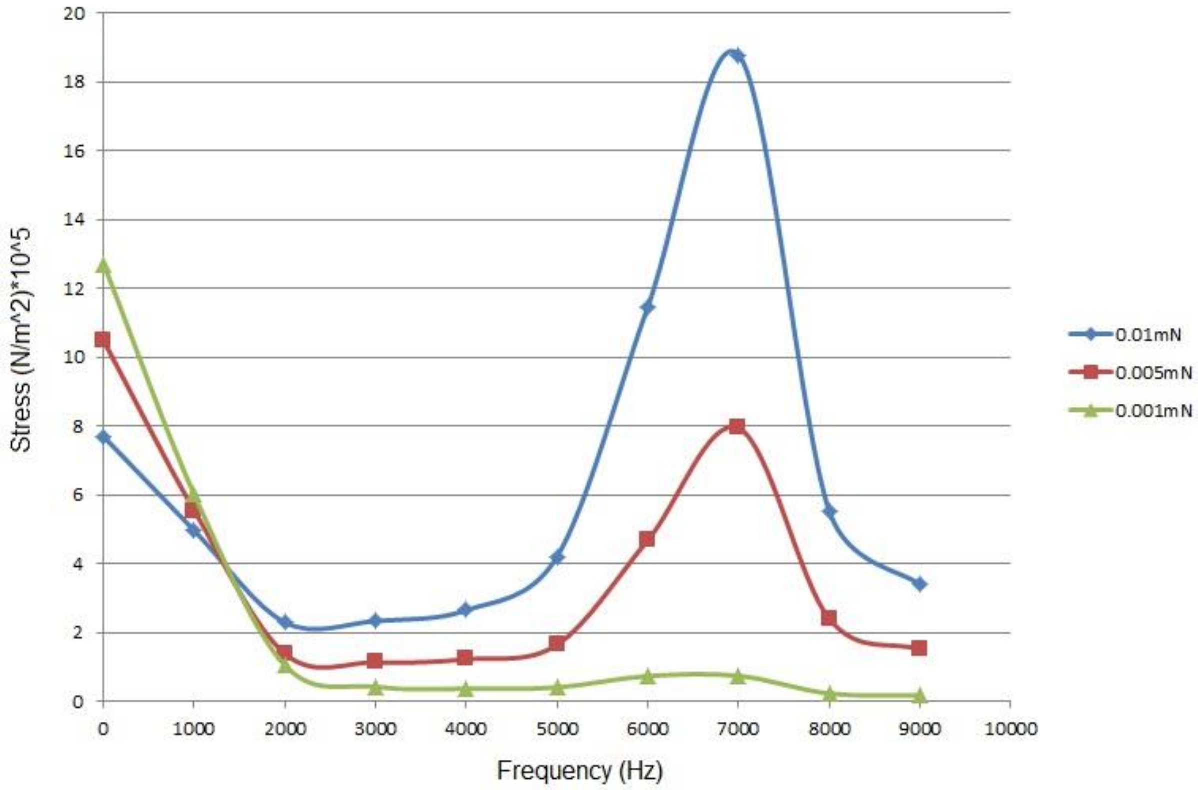

Figure 27. Stress Vs Frequency

CHAPTER-6

CONCLUSION

A MEMS PZT cantilever with an integrated Si proof mass is designed and simulated using a Pt/PZT/Pt/SiO2/Si/SiO2multilayer device for vibration energy harvesting. The integrated Si proof mass at the free end tip of the cantilever is used to decrease the resonant frequency of the device. The applied force of the micro power generator has been changed to obtain different frequencies. The measurement results show that the d31 mode piezoelectric MEMS generator had a maximum electric potential voltage of 0.541V at resonant frequency of 111Hz at the mechanical force of 0.0001mN. By using the arrays of micro generator systems can achieve high electric potential. The simulation results suggest that such structures can be used for energy generation in wireless sensor networks.

CHAPTER-7

FUTURE WORK

Our future work is to design a vibration-based MEMS micro power harvesting device consists of array of piezoelectric cantilever beam type power generation that provides the optimal desired output for power characteristics within high efficiency. This power is used for energy generation in wireless sensor networks.

CHAPTER-8
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[4]M. Marzencki, Y.Ammar, S. Basrour, *"Integrated power harvesting system including a MEMS generator and a power management circuit"* Sensor Actuators145–146 (2008) 363–370

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[7] S. Roundy, P. K. Wright, *"A piezoelectric vibration based generator for wireless electronics, Smart Materials and Structures"* 13 (2004)1131-1142.